CHAPTER 4

HOT WATER HEATING

Section I. DESCRIPTION OF EQUIPMENT

4-1. Definition

a. Description. Systems in which water is heated at a central source and circulated through pipes to radiators, convectors, or unit heaters are called hot water heating systems (fig. 4-1). There are two general types: the gravity system, in which water circulation depends upon the weight difference between the hot column of water leading to the radiators and the relatively cooler, heavier column of water returning from the radiators; and the forced-circulation system in which circulation is provided by a power-driven pump. With both types, provision must be made to allow for expansion of the water in the system as the temperature rises. This may be accomplished by an open tank mounted at the highest point in the system, or by a closed tank which may be located at any point. Water is heated to temperatures below boiling in a boiler and circulated to heat transfer elements similar to those used with steam systems.

b. Advantages and Disadvantages.

(1) *Advantages.*

(*a*) The system remains closed, and the same water may be recirculated indefinitely. As there is little fresh water added, the main source of air is minimized, and there is practically no corrosion or deposit of solids on boiler heating surfaces.

(*b*) The temperature of the water can be changed to meet weather conditions, and the temperature of the radiators can be varied over a wide range to match the load, giving an even heat output.

(*c*) Automatic traps, low-water controls, and other mechanisms requiring service are not needed.

(*d*) There is no problem of water hammer.

(2) *Disadvantages.*

(*a*) Because water temperatures are usually below steam temperatures, larger radiators or other heat transfer surfaces must be used.

(*b*) There is a greater possibility of water freezing in radiators and pipes remote from the boiler.

c. Open Systems. Open systems, in which expansion is provided for by a tank open to the atmosphere, are usually designed to operate at a maximum boiler temperature of 180° F. This gives an average radiator temperature of 170° F., or a radiator output of 150 B.t.u. per square foot.

d. Closed Systems. Closed systems, in which expansion takes place against an air cushion in a tank closed against the atmosphere, can be operated at temperatures above 212° F. as the pressure built up in the system prevents the water from boiling. Radiator temperatures can then be equal to those of low-pressure steam systems (para 3-1).

4-2. Boilers

a. Boiler Types. Boilers used for hot water systems are similar or identical with those used for steam systems and usually differ only in the waterline control, safety valve, etc. Round cast iron boilers can be supplied with either of two types of top sections, one for hot water and one for steam. The top section for steam boilers is larger so as to provide space for the separation and collection of dry steam. A typical rectangular cast iron sectional boiler is shown in figure 4-2. A vertical steel tubular boiler is shown in figure 4-3.

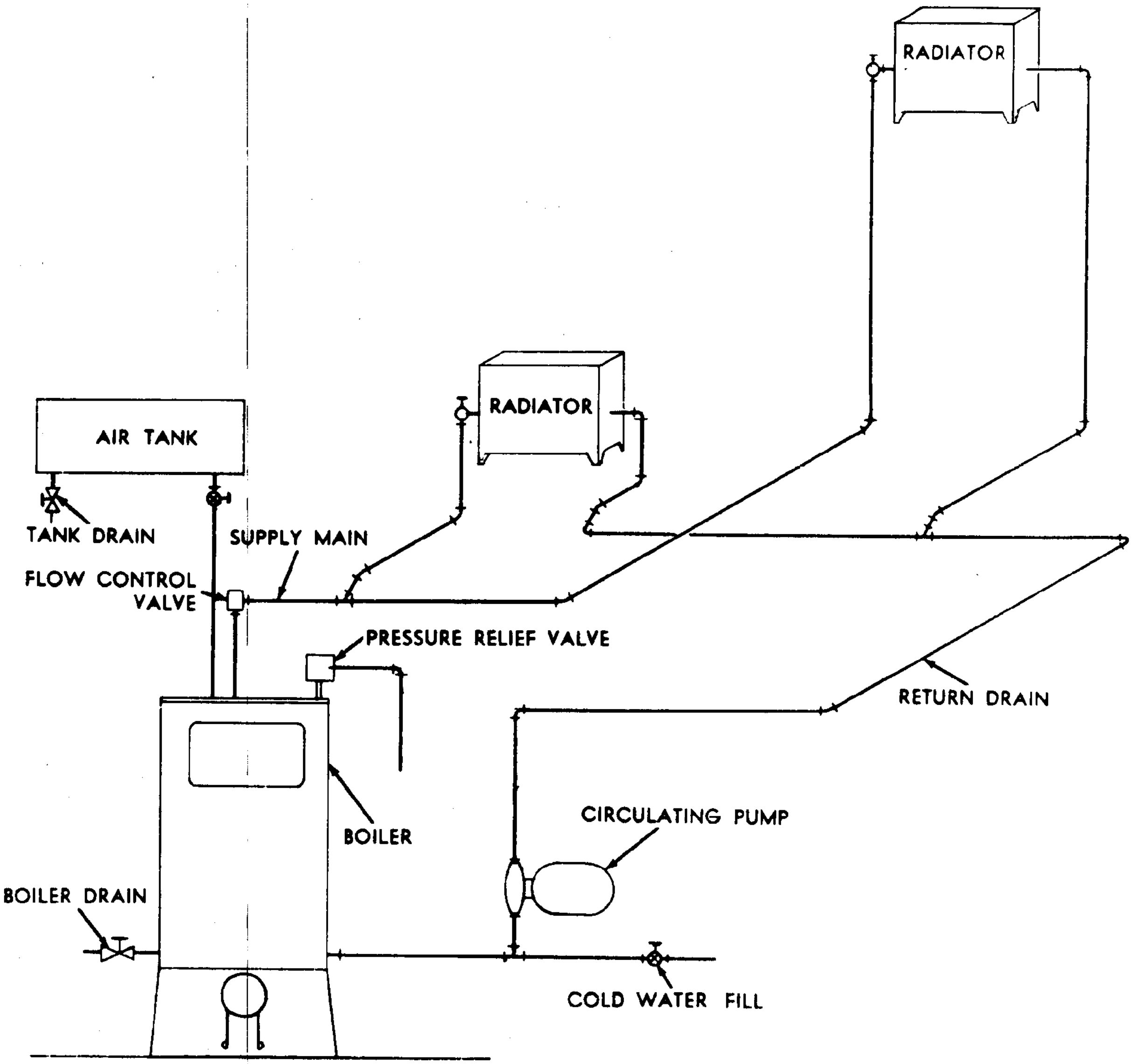


Figure 4-1. Forced-circulation hot water system.

b. Capacity Ratings. Hot water boilers are rated by the same associations and in the same manner as steam boilers (para 3-2*b*). Because of the variable heat output of hot water radiators, hot water boilers are usually rated in thousands of B.t.u. output. Where boiler ratings are given in square feet they are based on a heat emission of 150 B.t.u. per square foot.

4-3. Radiators, Convectors, and Unit Heaters

a. Description. Heat transfer elements used with hot water systems are almost identical to those used with steam systems (para 3-3). Minor differences are the type of air vents used and the fact that one is required at the top of each radiator of a hot water system. At least

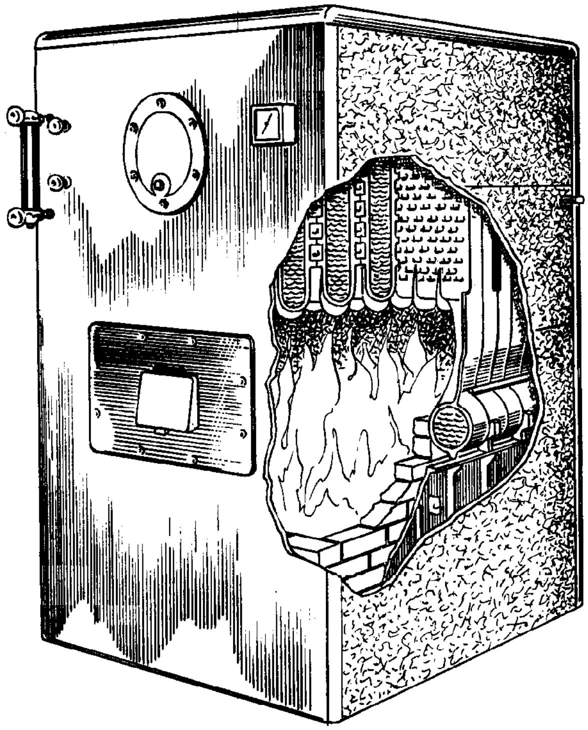


Figure 4-2. Cast iron rectangular sectional boiler.

one piping connection supply or return should be made at the bottom of each radiator to prevent stratification of hot water in the radiator. Up-feed supply risers must always be connected at the bottom of the radiator to prevent the riser from becoming air bound.

b. Rating. Heat transfer surfaces used with hot water systems are rated similarly to those used with steam systems (para 3-3*b* and app *H*).

4-4. Air Vents

a. Function. Air which may accumulate in a hot water system will find its way into the radiators, usually the highest ones, and, unless removed, will prevent the radiators from heating completely. This air must be removed by means of an air-vent valve at the top of the radiator. It is removed from all radiators when the system is filled for the first time, and may have to be removed at periodic intervals if the system is not kept full, or if fresh water is introduced.

b. Description. Simple manual vents operated by a key or screwdriver are most generally used (fig. 4-4). Where venting requirements are severe or maintenance is difficult, automatic radiator vents operated by a float or expanding disk can be used (fig. 4-5).

4-5. Valves

a. Function. Valves are used on hot water systems to:

(1) Turn off or regulate the flow of water to individual radiators.

(2) Balance the hot water distribution through the system.

(3) Prevent water flow in forced-circulation systems when pump is not in operation.

(4) Add water to fill the system either manually or automatically.

b. Description. Radiator cutoff valves (fig. 4-6) are required on only the inlet side of hot water radiators. These valves frequently have a small hole in the seat to permit some circulation when the valve is closed and to prevent freezing of the radiators in cold weather. The balancing of water flow to individual radiators or to sections of the system can be accomplished by use of square-head balancing cocks (fig. 4-7). These cocks require a wrench for adjustment and thus prohibit tampering by unauthorized personnel. A typical flow control or check valve is shown in figure 4-8. These valves are used to prevent gravity circulation in forced-circulation systems when heat is not required. Some of them can be opened or closed manually by an external lever. Be careful in their selection and installation to make certain that they open in the direction of water flow and that they are installed in the position, either horizontal or vertical, in which they were designed to operate. Water supply lines to manually filled systems, which include all systems with open expansion tanks, are equipped with a hand valve to turn off the water supply when all radiators are full. On closed systems this valve may be replaced by an adjustable pressure-reducing valve to automatically keep the system filled with water. These valves are selected and adjusted to maintain sufficient pressure to force water to the highest radiator.

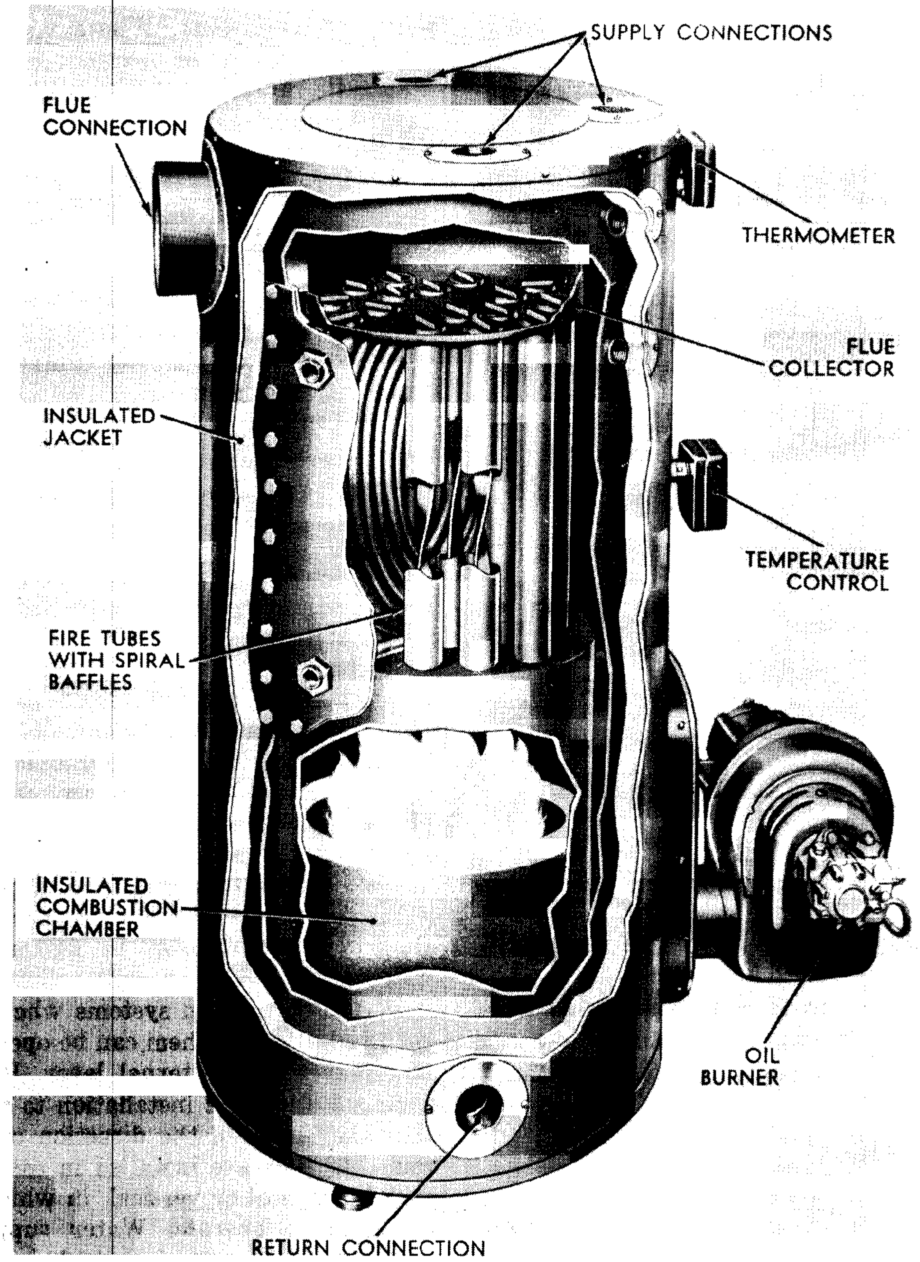


Figure 4-3. Steel vertical tubular boiler.

If system pressure is adjusted higher than necessary, it may reduce the air volume in the expansion tank beyond that required to allow for expansion of the water when the system heats up, and result in the spillage of water through the relief valve.

4-6. Circulating Pump

a. Function. The use of a circulating pump on a hot water system, although it introduces a moving part which requires a source of energy and regular maintenance, has the following advantages:

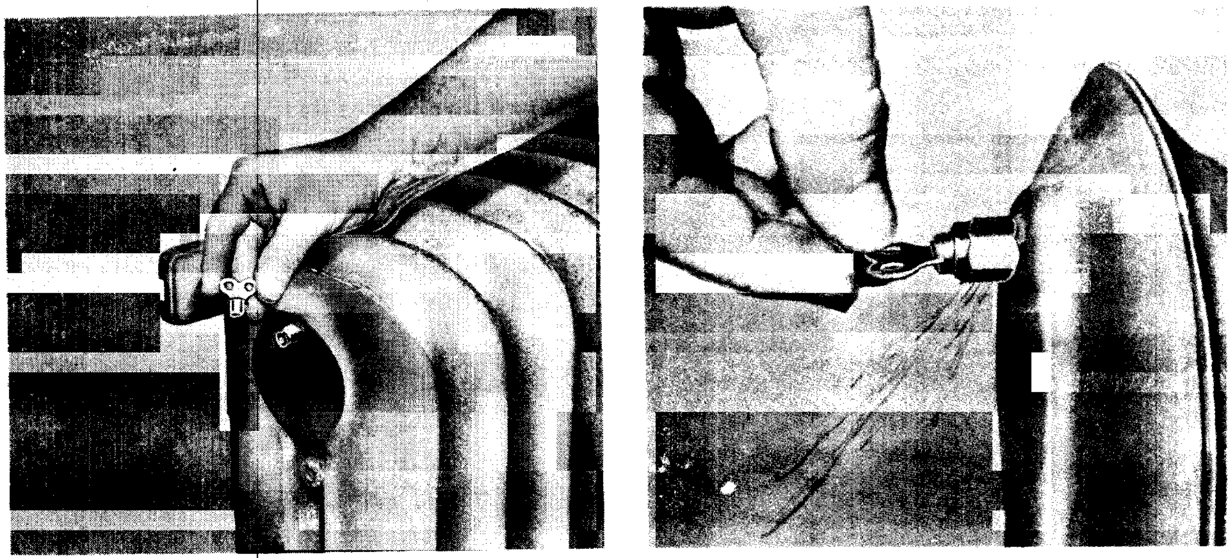


Figure 4-4. Manual radiator vent.

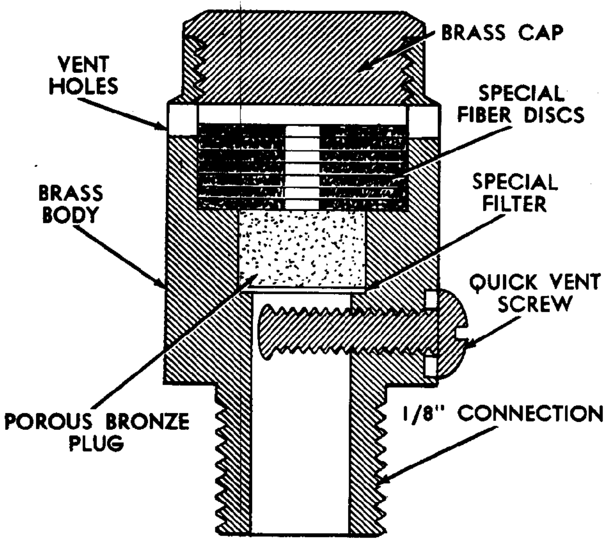


Figure 4-5. Automatic radiator vent.

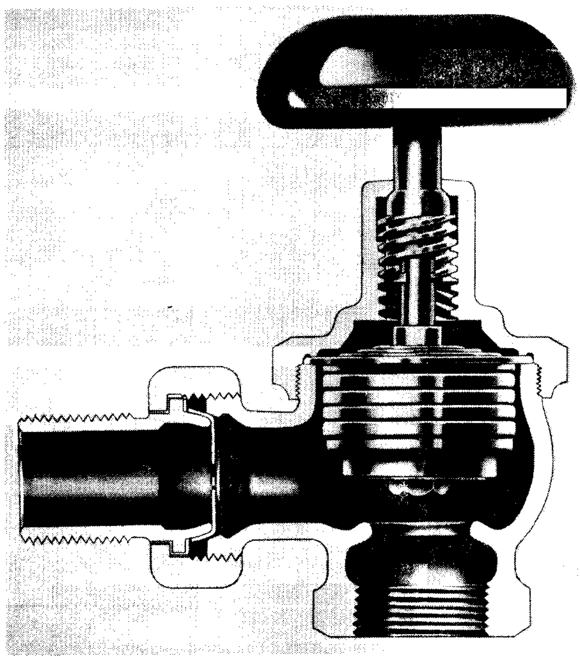


Figure 4-6. Radiator cutoff valve.

(1) It permits the use of smaller pipe sizes.

(2) It gives positive circulation without too much concern in the selection of pipe sizes.

(3) It permits one boiler to provide several separately controlled services, such as the supply of service hot water along with building heating or the heating of several buildings or zones in one building, each served by a separate circulating pump.

b. Description. Circulating pumps are almost always of the centrifugal type driven by a directly connected electric motor (fig. 4-9), al-

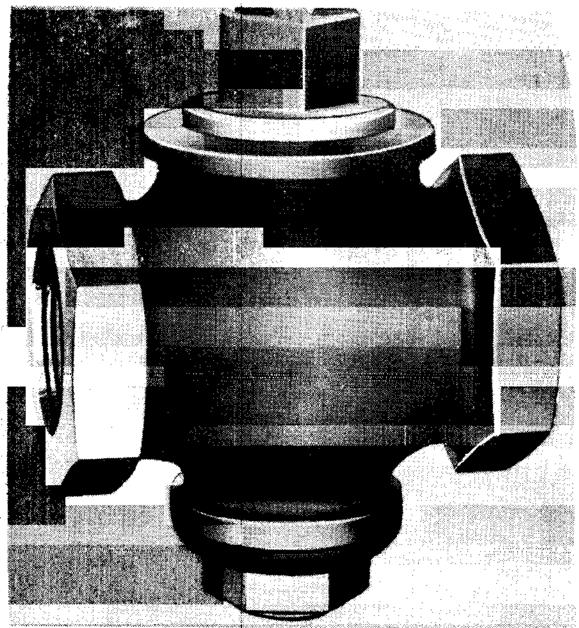


Figure 4-7. Square-head balancing cock.

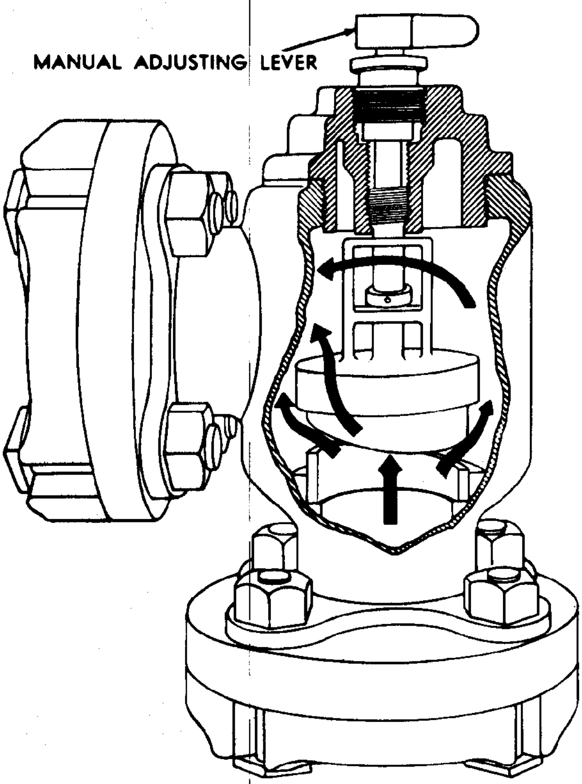


Figure 4-8. Flow control valve (angle type).

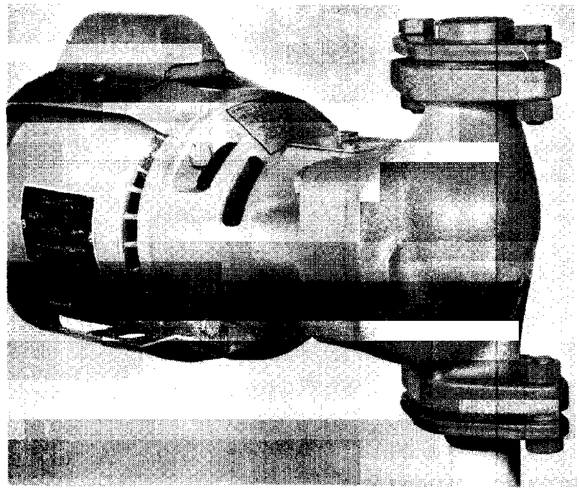


Figure 4-9. Electric motor-driven circulating pump for hot water system.

:hough other types of pumps and sources of ɔower can be used.

4-7. Piping

Steel piping with threaded joint or hard copper tubing with soldered joints is commonly used for hot water heating systems. Equipment such as circulating pumps, automatic valves, or radiators are installed with unions to permit easy removal for repairs or replacement. For detailed information on methods of assembling steel pipe or copper tubing see TM 5-746.

4-8. Tools

Pipefitting equipment sets Nos. 1 and 2 are required for the assembly of steel piping or hard copper tubing. For information on their use see TM 5-461.

Section II. DESIGN OF HOT WATER SYSTEMS

4-9. Sizing of Equipment

a. Radiators. The total amount of hot water radiation required in square feet to heat a given space is determined by dividing the total heat loss of that space (para 2-2 through 2-10) by the proper heat emission factor for the water temperature used. Heat emission factors for various temperatures are given in table 4-1. Where boiler water temperature is not specified, a temperature of 180° F. at the boiler is assumed and a radiator heat emission of 150 B.t.u. per square foot is used.

Example:

Given: Heat loss of room is 8,500 B.t.u. per hour and boiler water temperature is 200° F.

Then: Radiator heat emission = 188 B.t.u. per square foot (table 4-1) and required radiator capacity = $\frac{8{,}500}{188}$ = 45.2 square feet.

Table 4-1. Heat Emission Factors

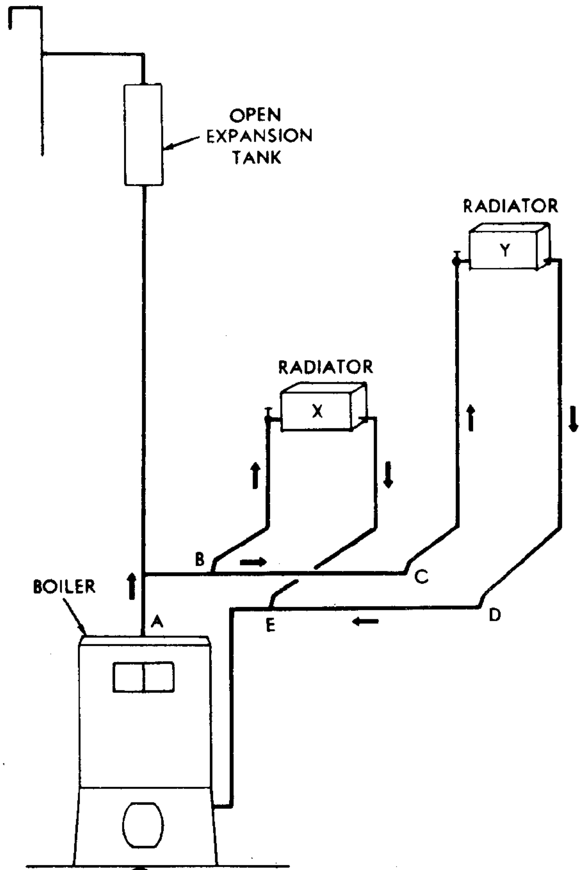
Boiler temperature in degrees F.	Average radiator temperature in degrees F.	Heat emission per sq. ft. of nominal radiator surface in B.t.u.
225	215	240
220	210	225
210	200	209
200	190	188
190	180	167
180	170	150

b. Boilers. Select boilers with a gross output which equals or exceeds the gross load, defined as the net load plus piping losses plus an allowance for pickup (para 2-8 through 2-10 and 3-2*b*).

4-10. Gravity Systems

a. Description.

(1) *Open two-pipe gravity system.* The majority of hot water gravity systems are open two-pipe systems (fig. 4-10). The water returns to the boiler by a direct route following the line of the supply mains making the system economical of pipe usage. Because the total length of circuit from the boiler to the radiator



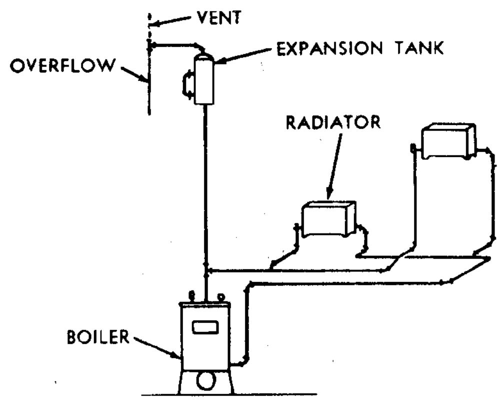


Figure 4-10. Open two-pipe gravity system.

and return is different for each radiator, these systems are somewhat difficult to balance and care must be taken in selecting pipe sizes, particularly for the larger systems.

(2) *Open two-pipe gravity systems with reverse return.* The problem of balancing water flow in two-pipe systems can be greatly reduced by use of the reversed return (fig. 4–10). In this system the first radiator connected to the supply main is the last radiator served by the return main so that the water travels in circuits of approximately equal length through each radiator. The chances that all radiators will heat evenly are greatly increased.

(3) *Open downfeed gravity systems.* Where a boiler is installed on the same level as the lowest radiator, a downfeed system (fig. 4–11) is used. In addition to simplifying the piping to the radiators on the same level with the boiler, this system, by carrying the supply riser as high as practicable in the same building, increases the head available to provide water circulation. Radiators may be connected in series as shown in *AA*, or in parallel as shown in *BB*. Where radiators are installed in series the size of subsequent radiators are increased to allow for the water temperature drop in the first radiator.

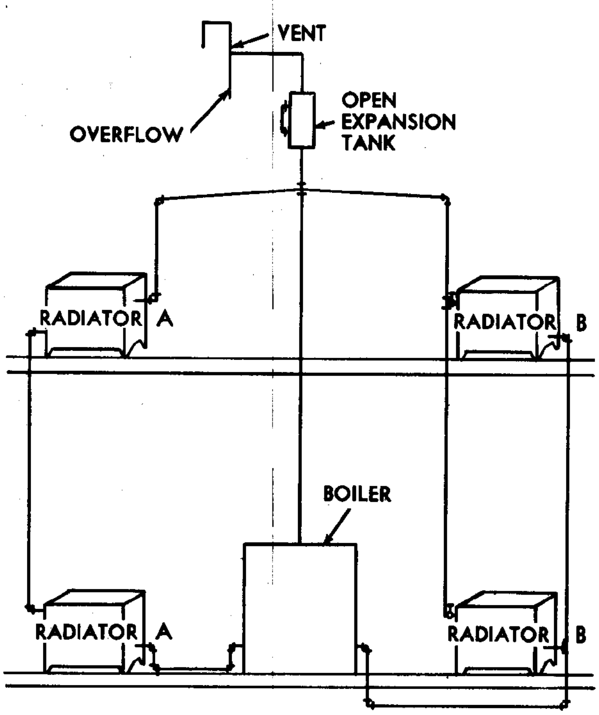


Figure 4–11. Open downfeed gravity system.

(4) *Open one-pipe gravity system.* Radiators can be installed with both supply and return risers connected to a single main. This system should be designed on the basis of a small temperature drop through the radiators so that the water reaching the last radiator is not too much cooler than the water reaching the first radiator. Because of the difficulty of getting sufficient circulation (to give this small radiator temperature drop) by gravity, these systems are not particularly recommended.

b. Pipe Sizing.

(1) *General.* Circulation in a gravity system is created by the difference in densities between the hot water in the supply system and the cooler water in the return system. It is opposed by friction in the system.

(*a*) *Available head.* The head available for water circulation varies with the difference in temperature between the supply and return and can be determined from figure J-1. This head is quite small and is expressed in milli-inches (thousandths of an inch).

(*b*) *Friction losses.* The friction losses of fittings and other parts of the system are usually expressed in terms of an equivalent number of elbows of the same pipe size. An elbow may be assumed to have the same friction loss as a length of straight pipe of the same diameter and 25 times as long as this diameter (nominal). The friction losses of various copper and iron fittings in terms of elbow equivalents are given in table J-1.

(*c*) *Selection of pipe sizes.* The heat-carrying capacities of iron and copper pipes at various friction losses are given in tables J-2 and J-3. Pipe sizes should be selected from this table so that the total resistance of each circuit is less than the available head.

(2) *Example:* As an example, pipe sizes will be selected for the two-pipe gravity system shown in figure 4–10. Assuming 180° F. flow temperature, 160° F. return temperature, 16 feet of head from center of boiler to center of highest radiator, output of radiator X 10

MBH, output of radiator Y 15 MBH, and the following pipe lengths: A-B 12 feet, B-C 20 feet D-E 20 feet, E-A 18 feet. Figure J-1 shows the available head for the temperatures given to be 82 milli-inches per foot of water column. The total available head is then 82 times 16 or 1,312 milli-inches. The piping must be sized so that the total resistance at the desired rate of flow does not exceed the total available head. The longest circuit, A-C plus D-A, is 70 feet, and, with 50 percent allowed for fittings, the total equivalent length of this circuit is 105 feet. The circuit must then be designed for 1,312 divided by 105, or 12.5 milli-inches per foot. Referring to tables in appendix J the recommended iron pipe sizes are:

Section	Load, MBH	Size to 12 milli-inch per foot drop
A-B	25	1½″
B-C	15	1¼″
D-E	15	1¼″
E-A	25	1½″
B-X	10	1″
E-X	10	1″
C-Y	15	1¼″
D-Y	15	1¼″

4-11. Forced Circulation System

a. Description. Forced-circulation systems have the advantages of permitting smaller pipe sizes and of allowing radiators to be located even with or below the boiler without impairing water circulation through them. As is the case with gravity systems, forced-circulation systems may be one-pipe or two-pipe, upfeed or downfeed, and equipped with direct or reverse return. Although usually provided with closed expansion tanks, open tanks can be used.

(1) *Closed two-pipe forced-circulation system.* The general arrangement of pipe and radiators for two-pipe forced-circulation systems is the same as for two-pipe gravity systems. The relative locations of circulating pump, compression tank, and flow control valve are shown in figure 4-12.

(2) *Closed one-pipe forced-circulation system.* The general arrangement of a closed one-pipe forced-circulation system (fig. 4-13) is the same as for one-pipe gravity systems. Circulation to individual radiators can be improved by the use of special supply and return connecting tees as shown in figure 4-14. These tees, by an injecting action on the supply and ejecting action on the return, combine to use a portion of the velocity head in the main to increase circulation through the radiators. These tees also aid stratification of hot and cold water within the main. They are designed to take off the hottest water from the top of the main and to deposit the colder return water on the bottom. Manufacturers' directions should be followed in the selection and installation of tees, particularly as to whether they are used for supply or return service and whether the radiator served is above or below the main.

b. Pipe Sizing. Friction losses in forced hot water systems are usually held between 600 and 250 milli-inches per foot although final design may be determined by the capacity of the pump available, as shown in manufacturer's data. After the available head has been determined, pipe sizes can be selected by the same method and same chart used for the design of gravity systems (para 4-10).

4-12. Radiator Location

As with steam radiators, hot water radiators are located close to the greatest source of heat loss. This will, in almost all cases, be along an outside wall, possibly under windows where warm air currents rising from the top of the radiator will counteract the cold air which tends to fall from the cold glass surface and spread out over the floor. On gravity systems, install the boiler well below all radiators to insure adequate circulation through them (para 3-16).

4-13. Zoning

a. Purpose. Forced hot water systems lend themselves readily to division into separately controlled zones. This is advantageous when the system is large and serves two or more spaces with varying load requirements. Zoning may also be advantageous when spaces have different hours of use, desired temperatures, or degree of exposure to sun and wind.

b. Methods. Zoning may be accomplished by the use of separate circulating pumps for each zone or by the use of one circulator with zone valves.

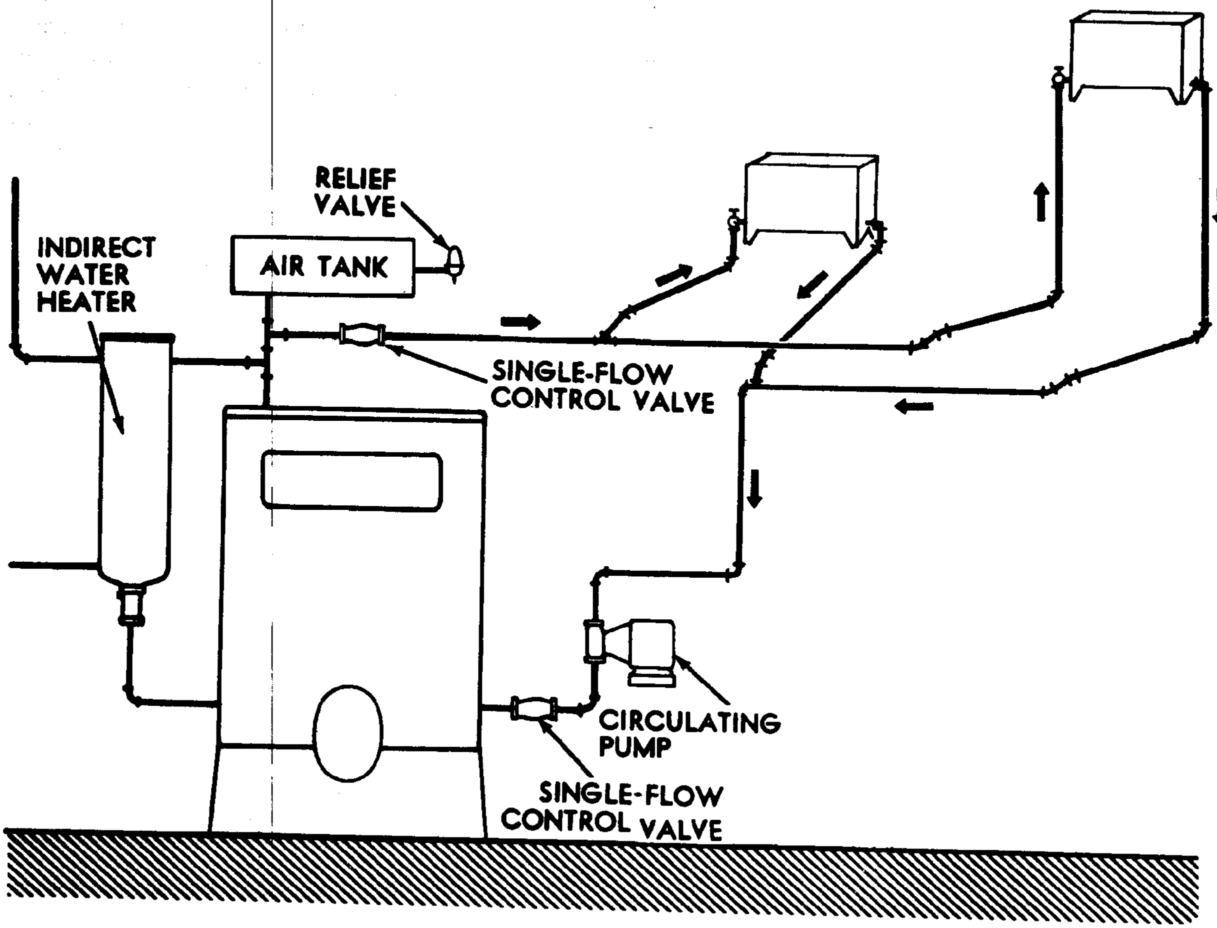


Figure 4-12. Closed two-pipe forced-circulation system.

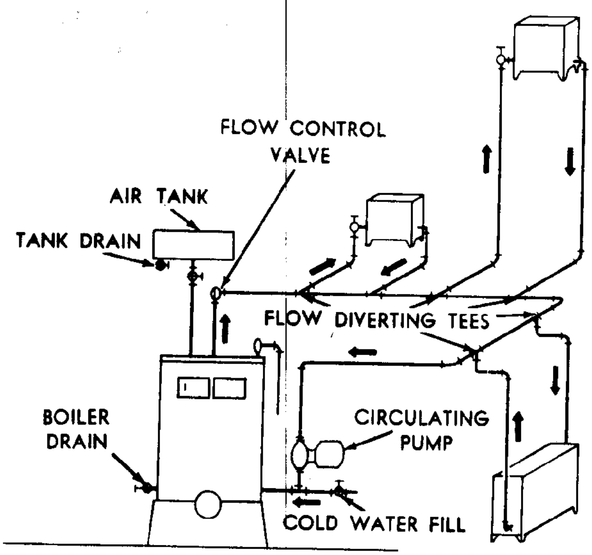


Figure 4-13. Closed one-pipe forced-circulation system.

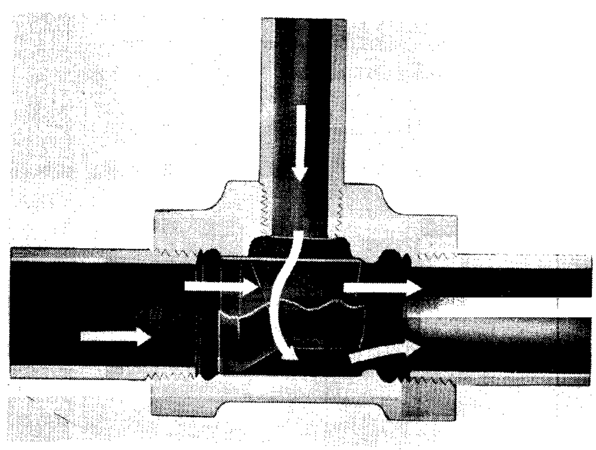


Figure 4-14. Radiator connecting tee for one-pipe system.

(1) *Multiple pumps*. Multiple pump zone systems are always used on larger systems using boilers of over 500,000 B.t.u. per hour output capacity or where piping pressure loss requires the use of a pump with a very low by-pass loss. These pumps will not tolerate a large reduction in water flow rate without overloading the motor.

(2) *One circulator with zone valves*. On small installations such as ordinary residences, the zoning loads are close to balance and a special pump called a circulator is used. This pump has a very high bypass factor and will operate at a closed-off load without stalling the motor. Each zone is controlled by a thermostat operating a zone valve controlling water flow through the particular zone. The end switches on the zone valves are all wired in parallel so that closing any of the end switches by opening the valve will start the circulator. Thus the circulator may operate with one or all of the zones or any number in between calling for operation. Where systems are zones, boiler operation, if automatic, is controlled to maintain a constant boiler water temperature as long as one or more zones are calling for heat. The water temperature controls are usually connected in with the power to the circulator. Thus, the boiler fuel supply is controlled along with the circulator. An additional control, called an indoor-outdoor control, is sometimes used to act as a water temperature limit responding to changes of outside temperature. This control changes the maximum operating water temperature inversely with outside temperature. As the outside temperature drops, thereby increasing the heat loss of the structure, the control raises the maximum water operating temperature. This action permits longer pump operating time and more even temperatures in the occupied area.

4-14. Expansion Tanks

Water, when heated in a hot water heating system, may expand as much as 4 percent over its original volume. To permit this expansion without damage to the system, an expansion tank should be provided. This tank may be open or closed.

a. Open Tanks. An open tank, as illustrated in (1), figure 4-15, has one connection open to the

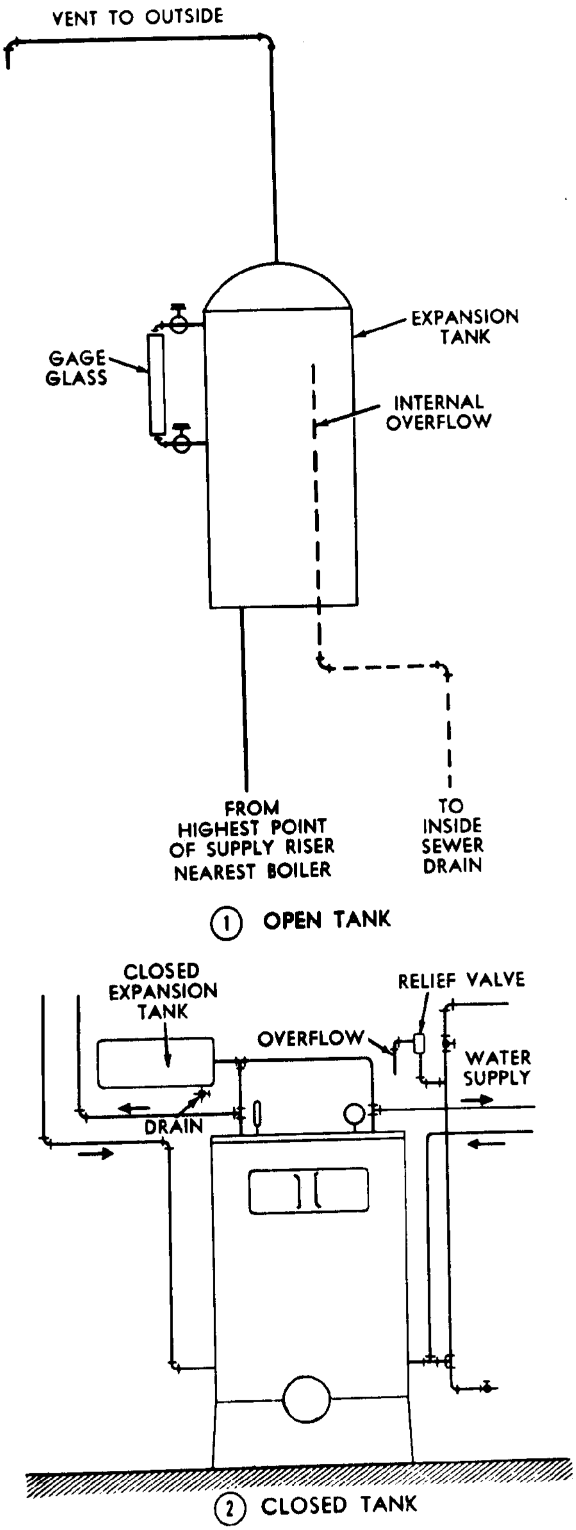


Figure 4-15. Connection of expansion tanks.

atmosphere so that expansion takes place against atmospheric pressure. Control of water feed to systems using open tanks must be by manual valves.

(1) *Method of connection.* In order to keep all radiators full of water, install open tanks above the top of the highest radiator (1), (fig. 4-15). When installed in cold climates, tanks are so located or connected that the vent cannot become closed by freezing of water overflow. One method of protecting the vent is the use of an inside overflow pipe. Where possible connect the expansion tank to the system near the top of the supply riser from the boiler so that air driven off from fresh water entering the boiler will find its way into the expansion tank and not be trapped in the radiators.

(2) *Sizing.* Suggested sizes for open expansion tanks are given in table K-1.

b. Closed Tanks. A closed expansion tank and the system to which it is connected ((2), fig. 4-15) is sealed against venting to the atmosphere. Expansion of water takes place against a cushion of air confined within the tank. The use of a closed system permits the automatic addition of water when required by means of a water pressure-regulating valve. Because the system is closed, a pressure-relief valve must be provided also to serve as a safety device in case the air cushion is lost or the tank is inadequate.

(1) *Method of connection.* Closed expansion tanks can be located anywhere in the system. Protect them against freezing, and for convenience of inspection generally locate them close to the boiler as shown in (2), figure 4-15.

(2) *Sizing.* A table of recommended tank sizes for closed systems is given in table K-2.

4-15. Insulation

Supply and return mains of hot water heating systems are seldom insulated in heated areas. When located in attics, pipe closets, unheated areas, or outside of buildings, they must be properly insulated, particularly if they are exposed to freezing weather. One-inch corrugated air-cell asbestos, weatherproofed where necessary, should be sufficient unless exposed to freezing temperatures, where 2-inch insulation should be used. The method of installing this material is discussed in paragraph 3-17.

Section III. CONTROLS

4-16. Purpose

Controls for hot water heating systems are of two types: operating controls which actuate and regulate the operation of a system so that it meets the heat requirements of the space it serves; and safety controls which protect the system and the building in which it is installed from damage due to faulty operation. Operating controls provide for both flow of heat when required and reduction or prevention of heat when it is not required, and thus save fuel. A hot water heating system, because it is normally filled with water and may be open to the atmosphere, is usually considered less hazardous than a steam heating system. Nevertheless, controls to prevent excessive water temperature or pressure are necessary.

4-17. Operating Controls

a. Thermostats. The types of room thermostats used with hot water systems and the principles of their application and location are similar to those applying to steam heating systems. A detailed discussion of room thermostats is given in paragraph 3-19*a*.

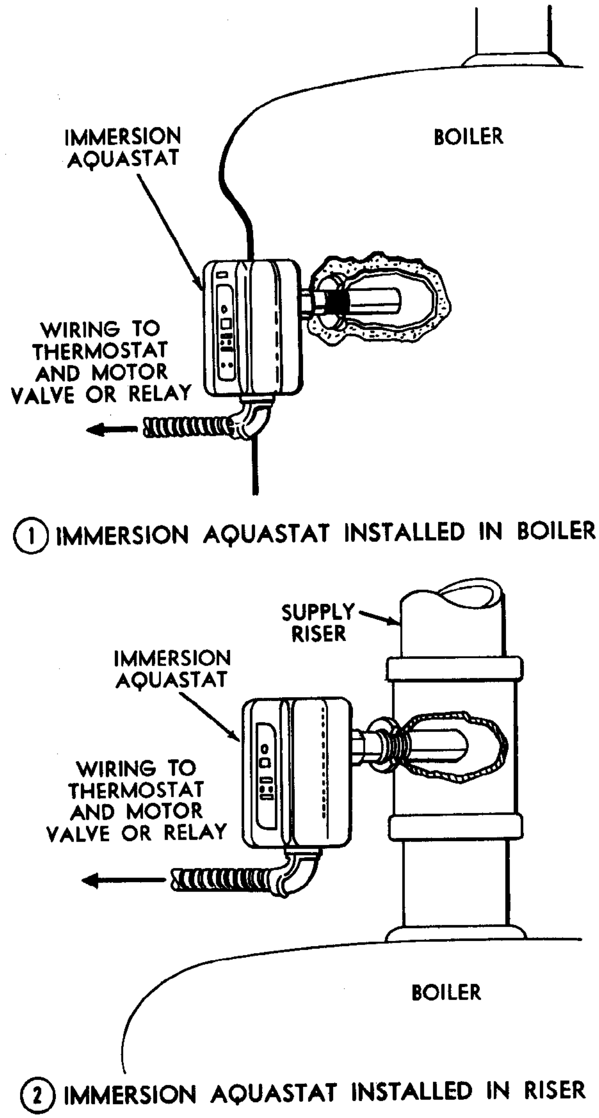
b. Boiler Water Temperature Control. When direct control by a room thermostat is impractical, boiler operation can be controlled by boiler water temperature using a water thermostat or "aquastat." These aquastats are identical with those used to limit boiler water temperature to a safe figure and are discussed more thoroughly in paragraph 4-18*a*.

c. Boiler Control. Automatically fired hot water boilers are usually operated most economically when they are controlled directly by a room thermostat. This is the accepted practice where the system is a gravity type. With forced circulation using multiple pumps or circulator with or without zone valves, the thermostat usually controls the operation of the pump or circulator or the circulator indirectly through the zone valve operation end switch when zone valves are used. The boiler water is then kept at a constant temperature so as to have heat available upon demand of a pump or circulator. This may also be the case where the boiler is also used to heat water for domestic service through an internal domestic water coil. To promote more even occupied-area temperature through longer pump operating cycles, an indoor-outdoor controller is sometimes used. Having one temperature-sensing bulb in the boiler water and one bulb located outside of the building on the side having the coldest exposure (usually the north or northwest side), this control varies the boiler operating water temperature according to outside temperature. As the outside temperature lowers, increasing the heating load, the control automatically increases the heat supplied by raising the boiler operating water temperatures. These controls are usually available in a multiple choice of changed ratios to fit the particular climate and design conditions. The manufacturer's specifications should be consulted for exact information.

d. Pump Control. Closest control of room temperatures will be obtained when the circulating pump is controlled directly by a room thermostat. For automatically fired boilers performing a single service, the boiler and pump will operate simultaneously.

4-18. Safety Controls

a. Temperature Limit Control. Every automatically controlled hot water boiler should be equipped with a high-temperature-limit control or "aquastat." This control should be set at least 10 degrees below steaming temperature and may be set lower if it is desired to limit the maximum water temperature for purposes of operational control. Where boiler operation is under the direct control of an aquastat, an additional water-temperature control must be installed to serve as a safety-limit control. Aquastats may be of the immersion type for installation within the boiler or supply riser (fig. 4-16), or of the surface type for installation in contact with the external surface of the supply riser (fig. 4-17). This type of aquastat is not recommended for riser-pipe sizes of less than 1½ inches because of the small contact area. In



Figur 4-16. Immersion aquastat installed.

the installation of the immersion aquastat, make certain that the water surrounding the immersion well has free circulation over the entire length of the well. Every closed hot water system, particularly those equipped with automatic water feed, should have a high pressure-relief valve. These valves are spring loaded and provided with a manual lever to check their operation (fig. 4-18). Relief valves are set to relieve pressure at slightly higher than the maximum working pressure. This will vary with the height of the building served and the water temperature desired. If the relief valve passes water regularly as boiler water temperature rises, check the condition of the closed expansion tank and make certain that th air cushion has not been lost and the tank has not become waterlogged. If air has been lost, close off the tank from the heating system with a manual valve and drain it. Then close off the drain and reopen the valve between the tank and the system. Although pressure-relief valves usually are used only on closed systems, they may be installed on open systems to guard against pressure buildup in the event that the expansion-pipe vent becomes clogged by ice or other material.

b. Temperature and Pressure Gages. Hot water boilers should be equipped with a thermometer or temperature gage and a pressure gage to permit the operator to check the condition of the system. Pressure gages are usually calibrated in feet of head so that the operator can tell whether the system has been filled to a sufficient pressure to force water to the top of the highest radiator.

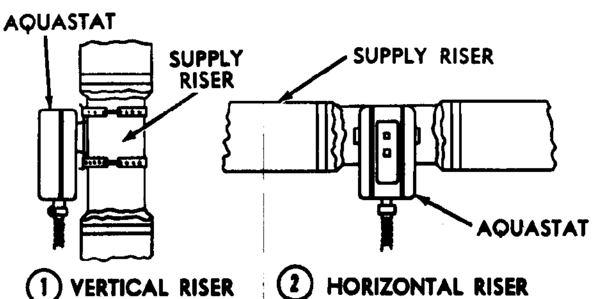


Figure 4-17. Installation of surface-mounted aquastat.

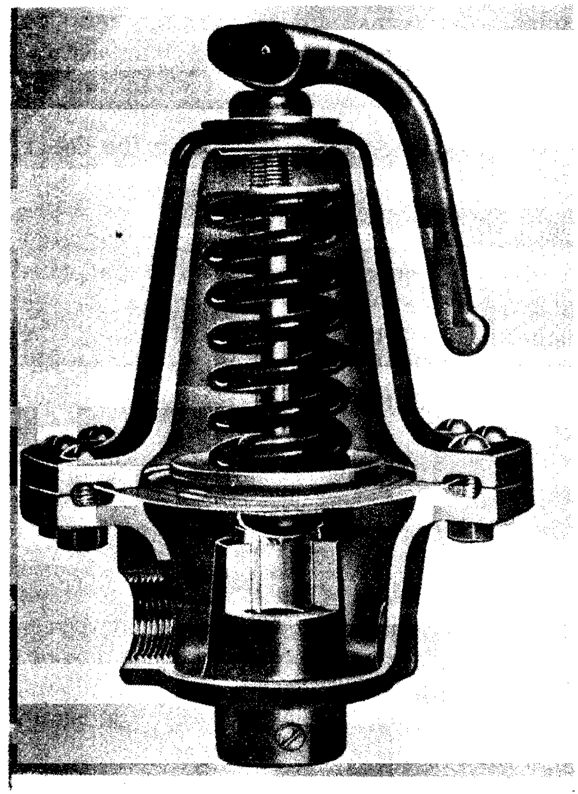


Figure 4-18. Pressure-relief valve.

Section IV. INSTALLATION

4-19. Location Selection

Hot water heating systems are installed and maintained in accordance with the information presented in this manual, TM 5-644, TM 5-650, and TM 5-652. Boiler location is usually dictated by chimney location since the flu connection should always be as short and direct as possible. When there is a choice, the boiler should be located as centrally as possible with respect to the radiators to be served. Problems of even heat distribution are simplified by shortening the distance from the boiler to each radiator.

4-20. Adjustment and Maintenance

Gravity hot water systems are seldom extensive enough to require further adjustment than can be accomplished by radiator valves. Forced hot water systems which are large, contain circuits of unequal lengths, or serve areas of different temperature requirements may require adjustment or balancing of water flow. A square-head balancing cock (fig. 4-7) is located at the return of each circuit to permit adjustment. Thermometer wells located in the returns ahead of the square-head balancing cocks are of great assistance in balancing the system. Balancing valves or orifices are installed in each radiator connection, if necessary, to obtain even heat distribution. Hot water heating systems require little maintenance other than periodic checking to make certain that all air is out of the system and that all radiators are full of water. Circulating pumps should be oiled regularly in accordance with manufacturers' instructions, and pressure-relief valves should be checked periodically.